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SALT LAKE DISTRICT
BUREAU OF LAND MANAGEMENT

TECHNICAL MEMORANDUM

A Comparison of Salt Thicknesses on the
Bonneville Salt Flats, Tooele County, Utah
during
July, 1960, October 1974, and October 1988
and Summary of Prior Investigations
by
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INTRODUCTION

The Bonneville Salt Flats (salt flats) consist of a hard salt crust and surrounding mud flats which form a unique geologic feature in northwest Utah (~~Figure 1~~^{Figure 1}). The overall shape of the salt crust north of I-80 is an elongate lens tapered at the northeast end and truncated by I-80 on the southwest. The area has been designed as an Area of Critical Environmental Concern (ACEC) by the BLM. The Bonneville Salt Flats Recreation Area Management Plan was completed by the BLM in 1985 which along with the Pony Express Resource Management Plan provide for retention of public lands, management, and preservation of the salt flats. The Pony Express Resource Management Plan also dictates that the ACEC be withdrawn from mineral entry, including leasing.

Reports of salt loss and deterioration have been received for more than two decades resulting in periodic studies and reports on the salt flats. The Pony Express RMP was protested by Reilly, Inc., owner and operator of the potash plant adjacent to the BSF resulting in a need to investigate the relationship between potash production and the quality and quantity of salt on the salt flats. A literature search was initiated. Of particular significance were survey of salt thickness conducted by Roy Tea of the Utah Department of Transportation in 1960 and 1974. The results of the survey were published in a "Report of Investigation No. 91, Bonneville Salt Flats: A Comparison of Salt Thickness in July 1960 and October 1974" by UGMS. The existing salt survey provided an opportunity to access long-term changes in salt volume by repeating the earlier survey. In order to determine the trend in salt volume, it was decided to conduct a new salt thickness survey in October 1988.

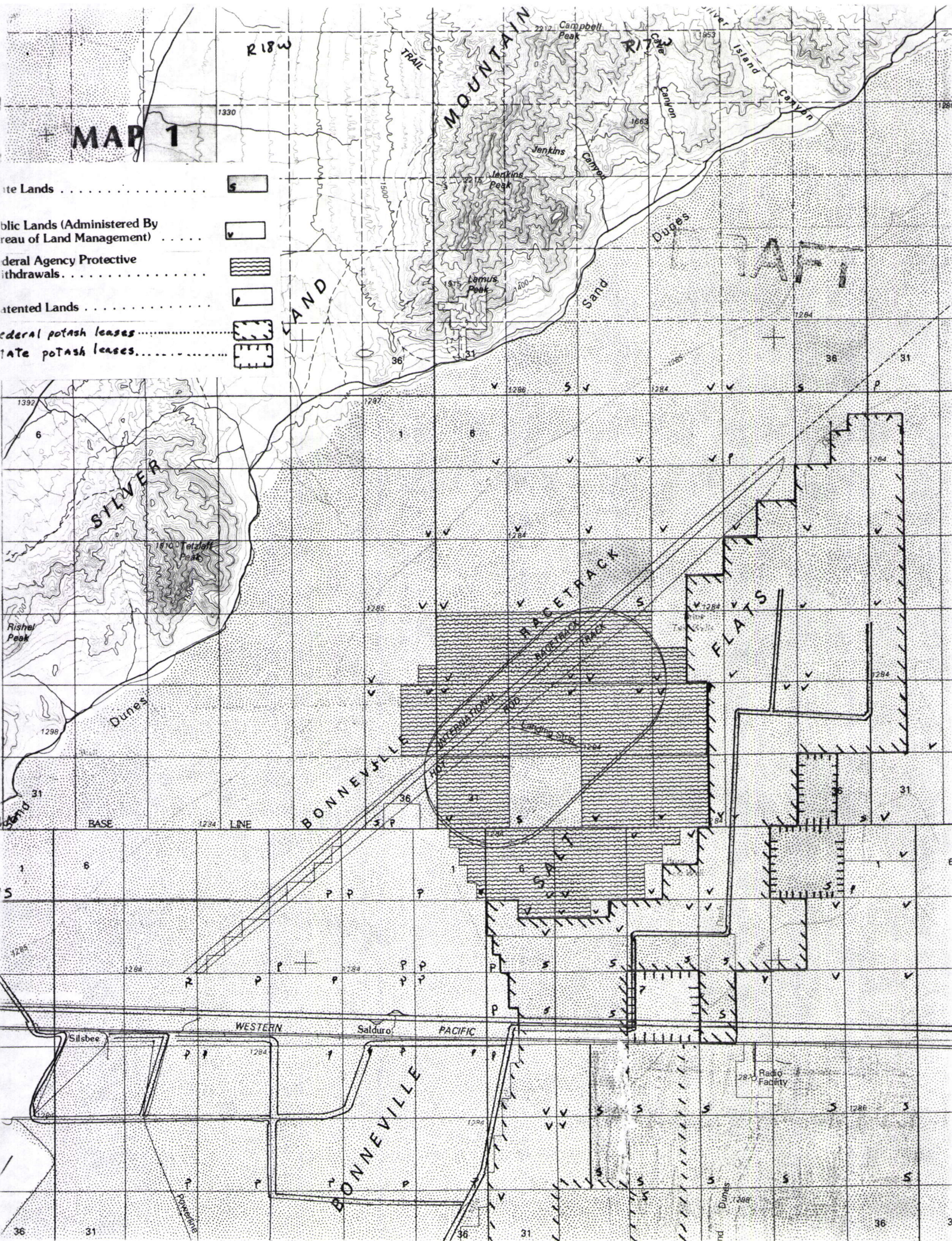
The purpose of this report is to determine salt thickness, volume, and distribution on the salt flats and provide the reader with an overview of the previous studies in the vicinity of the salt flats.

Copies of the original 1960 and 1974 survey notes listing salt thickness as determined by Roy Tea, Utah Department of Highways, District Two were obtained. The surveys consisted of a series of holes drilled to measure salt thickness in profiles across the raceway at one mile intervals along the straightaway. The results of the study were published in "Report of Investigation No. 91, Bonneville Salt Flats: A Comparison of Salt Thickness in July, 1960 and October, 1974." by UGMS.

PREVIOUS INVESTIGATIONS

The first known reference to a salt crust in northwest Utah was by Stansbury (1852, p. 110 and 111) in his description of crossing the northern part of Pilot Valley, in October 1849. Most

State potash leases.....



of his description would apply to conditions that existed in the fall of 1988, 139 years later. Stansbury wrote:

The first part of the plain consisted simply of dried mud, with small crystals of salt scattered thickly over the surface. Crossing this, we came upon another portion of it, three miles in width, where the ground was entirely covered with a thin layer of salt in a state of deliquescence, and so soft a consistency that the feet of our mules sank at every step into the mud beneath. But we soon came upon a portion of the plain where the salt lay in a solid state, in one unbroken sheet, extending apparently to its western border. So firm and strong was this unique and snowy floor, that it sustained the weight of our entire train, without at the least giving way or cracking beneath the pressure. Our mules walked upon it as upon a sheet of solid ice. The whole field was crossed by a network of little ridges, projecting about half an inch, as if the salt had expanded in the process of crystallization. I estimated this field to be at least seven miles wide and ten miles in length. How much farther it extended northward I could not tell: but if it covered the plain in that direction as it did where we crossed, its extent must have been very much greater. The salt, which was very pure and white, averaged from one-half to three-fourths of an inch in thickness, and was equal in all respects to our finest specimens for table use. Assuming these data, the quantity that here lay upon the ground in one body, exclusive of that in a deliquescent state, amounted to over four and a-half millions of cubic yards, or about one hundred millions of bushels.

Stansbury and his men camped at a spring on the west side of Pilot Valley for 3 days, and he wrote:

During our stay here, it rained almost every day and night. The salt plain, which before had glistened in the sunlight like a sheet of molten silver, now became black and somber: the salt over which we had passed with so much ease dissolved, and the flat, in places, became almost impassable.

Stansbury's description points out the dynamic nature of salt crusts and their sensitivity to even daily climatic changes. Indeed, if Stansbury had crossed Pilot Valley only 3 days later than he did, he would not have seen the Pilot Valley salt crust, and his description of the crossing would have been much different.

Gilbert (1890) studied the area covered by ancient Lake Bonneville, and he showed that the flats of the Great Salt Lake Desert are underlain by fine-grained calcareous sediments that were deposited in the lake. He noted that ancient shorelines of Lake Bonneville are at higher altitudes near the lake's geographic center than they are farther away. To explain this phenomenon, Gilbert postulated that the lake bottom had

differentially rebounded in response to weight loss when the lake water evaporated. Later investigation has substantiated Gilbert's theory of isostatic rebound (Crittenden, 1963).

The first comprehensive study of the shallow brines in the Great Salt Lake Desert was by Nolan (1928). Nolan hand-bored 405 shallow test holes in the desert and mapped the extent of the Bonneville and Pilot Valley salt crusts. On the basis of analyses of brine samples, he presented a map that shows the concentrations of chloride, potassium, and magnesium in the shallow brines in 1925.

Nolan concluded that differences in concentrations of potassium and magnesium in the brine were related to the quantity and chemical differences of surface-water runoff to different parts of the desert. He postulated that rebound of the bottom of Lake Bonneville near its geographic center (where the lake was deepest) and little or no rebound near its western border resulted in a westward tilting of the lake bottom. He suggested that the Bonneville and Pilot Valley salt crusts were the concentrated products of lake desiccation.

On the basis of carbon-14 dating of carbonate muds, Eardley (1962) worked out an evaporite history for the Great Salt Lake Desert. He believed that the Bonneville salt crust migrated westward 20-25 miles across the desert floor from its original site of crystallization in the center of the Bonneville basin. He concluded that rebound in the central part of the basin and wind ablation along the western edge created a westward tilt of the desert floor and that the Bonneville salt crust slowly migrated to its present location, aided by dissolving precipitation. Eardley (1970) has estimated that salt loss due to wind erosion amounts to 60,000 tons annually from the entire Great Salt Lake desert.

Kaiser (1967) conducted a series of short-term aquifer tests in a small area near the racetrack on the Bonneville Salt Flats. He concluded that two aquifers (the salt crust and underlying carbonate mud) exist and that there is little hydraulic connection between them.

Turk (1969) studied the hydrology of the Bonneville Salt Flats to evaluate the immediate and long-term potential of Kaiser's potash production. He presented a transmissivity map of the shallow-brine aquifer (the salt crust and carbonate muds) that was based on 82 aquifer tests conducted by personnel of Kaiser Aluminum and Chemical Corp., engineers from Utah State University, and by himself. He also presented maps of the Salt Flats that show the distribution of potassium and magnesium in the near-surface brines during 1965-67. Turk concluded that the collection of near-surface brines for potash production had selectively removed potassium and magnesium ions from the shallow brine aquifer while the salinity of the brine had been maintained by re-solution of the salt crust.

Stephens and Hood (1973) conducted a hydrologic reconnaissance in Pilot Valley, and Stephens (1974) conducted a hydrologic reconnaissance of the northern Great Salt Lake Desert. They concluded that three aquifers exist in much of the area: (1) an aquifer containing brine and composed of salt crust and the uppermost 25 feet of underlying carbonate muds, (2) alluvial fans that flank the mountains and contain fresh to moderately saline water, and (3) unexposed unconsolidated to consolidated valley fill that contains brine and is tapped by wells at depths of 1,000-1,600 feet in the Bonneville Salt Flats area.

The Utah Geological and Mineral Survey (1974) compared measurements of the thickness of the Bonneville salt crust made in 1960 and 1974. Both sets of measurements were made by personnel from the Utah Department of Transportation in a series of holes that were drilled at 1-mile intervals perpendicular to the racetrack. Comparison of the measurements indicated that north of Interstate Highway 80 the volume of the salt crust had decreased about 15 percent, and the area of the crust where the salt was thicker than 0.1 foot had decreased by about 9 percent.

Turk (1978) was commissioned by Kaiser Aluminum and Chemical to prepare a report in response to the Lines Report (1979). Turk (1978) pursued a three track approach consisting of air photo and satellite imagery interpretation on the Salt Flat (Track I). A study of brine hydrochemistry in an attempt to determine the area from which brine has been withdrawn. This was accomplished by mapping the extent of brine dilution with respect to potassium chloride and magnesium chloride by comparing brine analyses made in the 1960's to brine analyses made in the 1970's (Track II). Track III had the same objective as Track II, but used draw down observed in wells to do computer modeling of areas from which brine has been withdrawn in recent years.

Dames and Moore (1978) were contacted by BLM to prepare an inventory and market analysis of the potash resource of the Great Salt Lake by the Bureau of Land Management. Dames and Moore used existing data to prepare isocon maps of KCl concentration. Grades range from .5 to 3.0 KCl. The average saturated thickness of the shallow brine aquifer was estimated to be 19 feet. Porosity in the aquifer, including salt crust is 45% and weighted average KCl grade throughout the salt flat is 1.28 percent. The specific yield is 10%, subject to recharge by meteoric water which sustains progressively diluted brine flow (with respect to KCl and MgCl₂ concentration). Salinity in the shallow brine aquifer is maintained by solution of the salt crust. The economic KCl reserves in the shallow aquifer above a 0.40 weight percent KCl is approximately 19,072,276 tons, which includes the Bonneville raceway and other nearby areas not leased for potash.

Groundwater monitoring wells along the Bonneville dike of the

West Desert Pumping Project show that groundwater gradients have changed since the West Pond was filled, Waddell, Gwynn, and Burden (1988). It appears that the gradient was slightly eastward prior to filling the pond and is now in a westerly direction from the pond. However, no trends indicating changes in the chemical composition have been observed in the groundwater since monitoring began.

Lines (1979) studied the hydrology and surface morphology of the Bonneville Salt Flats and Pilot Valley playa. This summary of Lines (1979) work includes a section on hydrology and morphology of the Salt Flats and a section on measures evaluated to resolve conflicts on the Salt Flats.

Evaporite minerals on the Salt Flats and the Pilot valley playa are concentrated in three zones: (1) a carbonate zone composed mainly of authigenic clay-size carbonate minerals, (2) a sulfate zone composed mainly of authigenic gypsum, and (3) a chloride zone composed of crystalline halite (the salt crust). Five major types of salt crust were recognized on the Salt Flats, but only one type was observed in Pilot Valley. Geomorphic differences in the salt crust are caused by differences in their hydrologic environments. The salt crusts are dynamic features that are subject to change because of climatic factors and man's activities. Lines (1979) noted that much of the Bonneville racetrack had become rougher and there had been an increase in the amount of sediment on the south end of the racetrack.

Groundwater occurs in three distinct aquifers in much of the western Great Salt Lake Desert: (1) the basin-fill aquifer, which yields water from conglomerate in the lower part of the basin fill, (2) the alluvial-fan aquifer, which yields water from sand and gravel along the western margins of both playas, and (3) the shallow-brine aquifer, which yields water from near-surface carbonate muds and crystalline halite and gypsum. The shallow-brine aquifer is the main source of brine used for the production of potash on the Salt Flats.

Recharge to that part of the shallow-brine aquifer north of Interstate Highway 80 on the Salt Flats is mainly by infiltration of precipitation and wind-driven floods of surface brine. Discharge was mainly by evaporation at the playa surface and withdrawals from brine-collection ditches. Some water was transpired by phreatophytes, and some leaked into the alluvial fan along the western edge of the playa.

Water in the shallow-brine aquifer was moving toward brine-collection ditches from distances of several miles from the ditch system in the fall of 1976 (Lines, 1979). The position of the major ground-water divide, however, indicates that brine in the shallow-brine aquifer under much of the Bonneville Racetrack was not draining toward brine-collection ditches. This is not to say

that halite in the racetrack area is not being affected by the ditch system, because large quantities of redissolved salt crust during most years are moved eastward across the ground-water divide into the area of influence of the ditch system by floods of wind-driven surface brine. The halite that is moved in solution across the divide is subject to direct infiltration into the aquifer. Some of the sodium chloride is also precipitated on the surface southeast of the divide when the surface brine evaporates, and it is subject to later re-solution and infiltration into the aquifer.

The position of the ground-water divide, and thus the area of capture of water by the ditch system is subject to change and is dependent upon other variables such as the amount of recharge in different areas of the playa and discharge from the ditch system and alluvial-fan wells. Prior to withdrawals from the brine-collection ditches, a ground-water divide probably did not exist across the center of the salt crust (Lines, 1979).

Based on records obtained from a recorder on a flume, located on a booster pump in T1S, R17W, section 18, SW $\frac{1}{4}$ SE $\frac{1}{4}$, Lines (1979) estimated that 680 acre-feet of brine containing 270,000 ton of salt were withdrawn from the shallow-brine aquifer between June 3 and August 7, 1976. Lines (1979) also estimated average yearly withdrawals by ditches north of I-80 to be 960 acre-feet (381,000 tons) between 1966 and 1972. An additional 2000 acre-feet (870,000 tons of salt per year) were estimated to flow laterally through the shallow aquifer from north of I-80 to ditches south of I-80. Thus the total salt loss north of I-80 was estimated to be 1,251,000 tons/year.

Salt-scraping studies indicate that the amount of halite on the Salt Flats is directly related to the amount of recharge through the surface (which causes re-resolution of halite) and the amount of evaporation at the surface (which causes crystallization of halite).

One of the objectives of Lines (1979) study was to evaluate possible remedial measures that might be implemented to resolve conflicts between users. Discussions in Lines (1979) report made it evident that there are conflicts between the main uses of the area (potash production, the major transportation route of Interstate Highway 80, and racing). The hydrologic environment on the Bonneville Salt Flats has been altered by man's activities; as a result, the delicate surface morphology of the playa is changing. The main concern is with the thinning or re-resolution of the salt crust in the area of the Bonneville Racetrack north of the interstate highway. The re-resolution of the crust is a natural process that occurs during wet weather cycles, but the re-resolution has been accelerated in some areas by man's activities which withdraw the brines.

Another major concern is with the deposition of sediment on large areas of the salt crust behind manmade drainage barriers (roadfills for the interstate highway and tailings piles along brine-collection ditches). In the man-made ponding area on the south end of the racetrack, the accumulation of sediment and accompanying re-resolution of the salt crust has rendered the surface unsuitable for racing. The movement of minerals, both on the surface and by subsurface flow, across lease and property boundaries is also of major concern.

METHODOLOGY-1988 Salt Thickness Study

The purpose of the study is to document long term trends in salt thickness, volume, and distribution. A little Beaver model 8 portable auger mounted on an all terrain vehicle was used to drill through the salt. Salt thickness was measured by inserting a hook and feeling the bottom of the salt. The salt thickness listed in Table 1 is total salt, which was obtained by adding the soft salt and hard salt thickness listed in the UDOT field books. The difference between hard salt and soft salt was an overly subjective criteria; difficulty in repeating measurements was encountered during the BLM survey.

Mile posts were marked along the raceway, and various distances left and right of the raceway marked by BLM Cadastral Surveyor, Glenn Hatch, using a transit and theodolite. Drill sites are shown on the isopach map in appendix 1, along with mileposts (mp), lease boundaries, and ditches. The arcuate ditch (Salduro ditch) is abandoned.

Salt locations and salt thickness for the 1960, 1962-65, 1974, and 1988 surveys are listed in Table 1, Appendix 3. (It should be noted that the 1988 raceway is about one-fourth mile southeast of the location in 1960 through 1974). UDOT reported a 15% loss in salt volume between 1960 and 1974. It has been speculated that the historically unprecedented wet weather cycle of the early 1980's, which resulted in flooding brine evaporation and concentration ponds in 1982, may have replaced a portion of the salt lost on the raceway. Mr. Roy Tea reported (verbal communication, October 1988) that there was a substantial flow of water from south of I-80 in the vicinity of the potash production facilities to north of I-80 through culverts under the freeway, and that additional culverts were installed under I-80 east of Wendover. Map 1 depicts land status in the vicinity of the Bonneville Salt Flats.

The total salt thickness from the 1960, 1974, and 1988 surveys were used to prepare an isopach maps 1,2, and 3 respectively. The isopach maps were generated from digitized drill hole locations using the CPS/PC program by Radian Corporation. The UTM coordinates for the drill hole locations and limit line are listed in appendix 1, along with the salt thickness measurements.

Discussion

In 1960 the 1.0 foot salt thickness contour closely followed the limit of calculation line along the northwest side of the salt crust. By 1988 salt thickness was reduced to 0.1 foot in the

vicinity of the limit line along the northwest edge of the salt crust. In 1960, 1.0 foot or more of salt crust occurred in the area where the more westerly ditches now drain brines for potash production north of I-80. By 1988 the area covered by 1.0 foot or more of salt on the southeast edge of the salt flat had moved about 1/2 mile northwest.

The salt volume decrease is as follows:

<u>Tons Salt</u>	<u>Year</u>
141,100,000	1960
118,100,000	1974
99,700,000	1988

The volume was calculated from the isopach map by planimetering areas and multiplying by the average thickness. The resulting volumes were converted to tonnage based on the 1.18 tons/yard³ conversion utilized by UDOT in the 1974 UGMS publication. Volume was determined within the limit of calculation line shown on the isopach maps. The limit line also demarcates the extent of the salt flats north of I-80.

The area north of I-80 covered by more than 1 foot of salt was 22,900 acres in 1960, 20,550 in 1974, and 19,000 in 1988.

CONCLUSIONS

An average of 1,479,000 tons of salt are removed from the salt flats north of I-80 each year. Using 1960 as the base for salt volume calculations results in a net loss of 29.4% in the following 28 years, or about 1% per year. This salt loss calculation compares well with the 1,251,000 tons/yr salt loss estimated from data presented by Lines(1979), pages 88-89. Lines estimated that 960 acre-feet of brine were collected per year from ditches north of I-80 and 2000 acre-feet per year flowing laterally through the shallow-brine aquifer toward ditches from north of I-80.

The area covered by 1 foot or more of salt was reduced by 11% between 1960 and 1974 and by 6% between 1974 and 1988.

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